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REVIEW ARTICLE

Systematic review of imaging comparisons of spinal alignment among standing positions in healthy adolescents or adolescents with idiopathic scoliosis: SOSORT 2023 award winner

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Abstract

Purpose Clinicians detect scoliosis worsening over time using frequent radiographs during growth. Arms must be elevated when capturing sagittal radiographs to visualize the vertebrae, and this may affect the sagittal angles. The aim was to systematically review the published evidence of the effect of arm positions used during radiography on spinal alignment parameters in healthy participants and those with AIS.

Methods Design was registered in PROSPERO (CRD42022347494). A search strategy was run in Medline, Embase, CINAHL, and Web of Science. Healthy participants ≥ 10 years old and participants with AIS between 10 and 18 years old, with Cobb angles > 10° were included. Study quality was assessed using the Appraisal tool for Cross-Sectional Studies (AXIS). Meta-analysis was performed where possible.

Results Overall, 1332 abstracts and 33 full texts were screened. Data was extracted from 7 included studies. The most common positions were habitual standing, fists on clavicle, and active (arms raised unsupported). Kyphosis, lordosis, and sagittal vertical axis (SVA) were most measured. Meta-analysis showed significantly decreased kyphosis (SMD = 0.78, 95%CI 0.48, 1.09) and increased lordosis (SMD = − 1.21, 95%CI − 1.58, − 0.85) when clavicle was compared to standing. Significant posterior shifts in SVA were shown in clavicle compared to standing (MD = 30.59 mm, 95%CI 23.91, 37.27) and active compared to clavicle (MD = − 2.01 mm, 95%CI − 3.38, − 0.64). Cobb angles and rotation were rarely studied (1 study).

Conclusion Meta-analysis evidence showed elevated arm positions modify sagittal measurements compared to standing. Most studies did not report on all relevant parameters. It is unclear which position best represent habitual standing.

Keywords Arm · Patient positioning · Radiography · Kyphosis · Lordosis · Review

Introduction

Adolescent idiopathic scoliosis (AIS) is a 3D structural disorder of the spine with lateral curvature of over 10°, vertebral rotation, and sagittal changes that affects 2–3% of adolescents [1]. Patients with AIS receive numerous x-rays throughout their treatment to establish the diagnosis and monitor curve progression, which is defined as a five degree increase in Cobb angle compared to previous radiographs. This exposes them to harmful radiation throughout their growing years. Particularly in young children, increased exposure to radiation has been shown to increase the incidence of cancer [2]. Ronckers et al. followed 5513 females with scoliosis, finding they were exposed to an average of 22.9 radiographs per person during treatment and follow-up [3]. Similarly, a Milwaukee-based program following 13 females with AIS estimated that each patient had 22 films taken during a three-year course and showed increased risk for leukemia (3.4%), stomach/gastrointestinal (1.3%), lung (7.5%), and breast cancers (110%) [4]. A 2012 SOSORT Consensus Report stated that scoliosis experts agreed x-rays should be performed at the time of first evaluation and then every 6–12 months afterward to minimize total number of x-rays [5].

All radiographic measurements, when imaging patients with AIS, depend on being able to see the detail of key vertebral landmarks while ensuring that the arm position used

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during the radiograph does not affect the sagittal and frontal spinal parameters. Sagittal views are necessary to measure spinal parameters such as kyphosis and lordosis. The Scoliosis Research Society (SRS) Radiographic Measurement Manual states an ideal standing lateral radiograph should include vertebrae C7 to S1 and the ability to visualize C0–C1 and the hip joints is optimal [6]. Key landmarks to assess kyphosis and lordosis include vertebrae T1/T2, T4/T5, T10-T12, L1 and the sacrum. Another key sagittal parameter includes sagittal vertical axis (SVA), requiring the x-ray to show the anterior–posterior position of vertebrae C7 relative to the superior posterior corner of the sacrum [7]. Historically, only frontal radiographs were collected, but research has demonstrated that sagittal deformity is more strongly related to quality of life [8]. Recently, low-dose radiographic systems have become available that simultaneously acquire a frontal and a sagittal image that reconstruct the spine in 3D [9]. It is necessary to have the arms elevated when using such systems in order to expose the whole sagittal plane of the spine and avoid the arms from overlapping with vertebral bodies. However, raising the arms has been shown to affect sagittal angles [7, 10–16]. Ideally, patient positioning during standing radiographs would reflect habitual posture parameters, or at minimum, be similar to the standing posture used to monitor frontal angles historically.

It would be beneficial to know which arm position used during imaging will simultaneously allow exposing the hands in order to determine skeletal maturity. Assessment of skeletal maturity can be done using the Sanders Skeletal Maturity Staging System. This system breaks down the fusion of the epiphyseal growth plates into 8 stages and can be used to determine how much growth a patient with AIS has left, and thus, estimate the scoliosis progression risk [17]. Risser staging has traditionally been the primary marker of skeletal maturity utilized in decision making for treatment of AIS because it is scored on routine frontal spine radiographs. This method requires determining ossification of the left iliac apophysis that is associated with the patient's state of spinal maturity [18]. Compared to Sanders assessment, Risser staging has been shown to result in suboptimal treatment in one in every four patients, with the vast majority being undertreated [18].

The aim of this study was to review and synthesise the published evidence of the effect of arm positions used during radiography on spinal alignment parameters compared to habitual standing in healthy populations and populations with AIS. Spinal alignment parameters of interest include Cobb angle, whole thoracic kyphosis, T5–T12 kyphosis, lordosis, AVR twist, and any other spinopelvic parameters such as sagittal vertical axis (SVA). Sagittal angles are a primary parameter of interest. We hypothesized that:

1. We will be able to identify an arm position that will allow exposing the hands for skeletal maturity assessment that does not significantly alter vertebral rotation, or any frontal or sagittal angles compared to habitual standing, and
2. The largest differences due to elevating the arms will be detected using sagittal angles (kyphosis and lordosis) compared to frontal or transverse measurements.

Methods

Design and methods used for this systematic review were registered with the International Prospective Register of Systematic Reviews (PROSPERO CRD42022347494). Reporting is compliant with Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [19].

Search strategy

The search employed sensitive topic-based strategies designed for each database from inception to June 29, 2022. Databases include Cumulated Index to Nursing and Allied Health Literature (CINAHL) (EBSCO), Embase (OVID), Medline (OVID), and Web of Science (All databases). The search syntax used in each database is reported in the Appendix. The strategy includes terms and keywords identified by an expert on scoliosis, a master's student, and by librarian Liz Dennett from the Health Science library at University of Alberta. The search for this review was designed by identifying terms related to the scoliosis population, imaging methods, measurements of interest, and patient positioning. To limit to the most relevant references, we eliminated any populations where scoliosis was a symptom of another disease. Covidence was used to import all articles, and duplicates were eliminated automatically. Covidence is a web-based collaboration software platform that streamlines the production of systematic and other literature reviews [20].

Study selection criteria

Studies were included if they focused on healthy participants aged ≥ 10 years old and participants with AIS between the ages of 10 and 18 years old with Cobb angles $> 10°$. Studies comparing the effect of patient positioning and arm positioning for full spine imaging, limited to standing, were included. Cohort or cross-sectional study designs where positions were compared within a short time interval were included. Studies with participants diagnosed with spinal disorders other than AIS, injuries to the lower body, and studies with pregnant participants were excluded.

Selection process

Two independent reviewers used Covidence to select relevant articles during a titles and abstract screening stage using the eligibility criteria outlined above. Reviewers were blinded to selections. For references meeting the criteria as identified by both reviewers, the two independent reviewers screened full text articles uploaded to Covidence. At both screening stages, if reviewers disagreed, they first had a consensus discussion, and if needed, a third reviewer made the final decision. Percent agreement was calculated between reviewers.

Data extraction

Two reviewers independently extracted study information using a piloted Google spreadsheet. Reviewers first tried extraction on three papers and discussed results before continuing further. During extraction, if reviewers disagreed, they attempted to reach consensus via discussion, then consulted the opinion of a third reviewer if needed. The reviewers extracted the following study information (where available); sample descriptions including age and sex, diagnosis, curve type and severity, imaging methods, spinal measurements, descriptions of testing positions, and reported statistics comparing the positions.

Scoliosis measurement parameters including maximum curve angle, axial vertebral rotation (AVR), sagittal angles including kyphosis and lordosis, SVA, and any other relevant spino-pelvic parameters were extracted. Statistical results comparing positions were extracted. Kyphosis and lordosis angles were considered the primary outcomes.

Risk of bias assessment

The Appraisal tool for Cross-Sectional Studies (AXIS) was used to determine the quality of cross-sectional studies [21]. The AXIS quality appraisal was scored out of 12 for the 12 questions referring to methodological quality to avoid focusing on reporting quality (Table 1). We selected "positive" when the answer to the question was clear and precise. An "unclear" result was given when the answer to the question was vague. A "negative" result was given if the study did not report on the question. Each study was given a final score out of 12, and a corresponding rating. Scores ranging from 1 to 3 were rated low, scores from 4 to 7 were moderate, and scores above and including 8 were rated high quality. AXIS has been shown reliable in comparison to an adapted Newcastle–Ottawa Scale (NOS) [22]. Both reviewers read the manual on AXIS grading, reviewed one article, compared results, and then appraised the rest of the papers. Both reviewers were trained in determining how to rate methodological questions sufficiently [21]. Both reviewers independently completed the appraisal for each selected article. Disagreements in quality scoring were resolved by consensus.

Data synthesis

Summary tables were prepared: including levels of evidence summary statements based on quality assessment, study characteristics, extracted descriptive statistics, and outcome characteristics reported in and missing from current literature. Meta-analysis was performed for each measurement parameter if more than two studies reported on a similar spinal parameter and arm positions using RevMan 5.4.1 (The Cochrane Collaboration, version September 2020. Available at revman.cochrane.org). We used a random-effect meta-analysis of standardized mean differences for kyphosis and lordosis due to differences in measurement scales reported in the articles. In contrast, a random-effect meta-analysis of the mean differences was reported for SVA measurements due to consistent measurement scales used for this parameter. Point estimates and 95% confidence intervals were reported for each meta-analysis. Chi-square tests of heterogeneity were performed and I^2 was reported for each meta-analysis. I^2 results were interpreted as follows; 0–40% may not be considerable heterogeneity, 30–60% may represent moderate heterogeneity, 50–90% may represent substantial heterogeneity, and 75–100% represents considerable heterogeneity [23].

Levels of evidence summary statements were formulated for other results. As adapted by Cornelius et al., the summary of results was graded using the levels of evidence (Table 2) considering the methodological quality and the consistency of the results across studies for each parameter and positions comparisons [24].

Results

Study selection

A total of 1440 studies were identified across all databases (MEDLINE = 78, EMBASE = 338, CINAHL = 65, WEB OF SCIENCE = 851) (Fig. 1). After 108 duplicates were excluded, 1332 abstracts and titles were screened by the two reviewers. After exclusion of 1299 irrelevant records, 33 full texts were screened by the two reviewers, and 26 studies were excluded. Seven papers were ultimately included for data extraction [7, 13, 14, 16, 25–27]. Percentage of agreement between the reviewers was 97.5% for title and abstract screening and 100% for full text screening.

Table 1 Axis quality assessment

	Pasha, 2016[16]	**Abe, 2015**[25]	**Wojciech, 2013**[26]	**Asano, 2015**[27]	**Marks, 2003**[14]	**Marks, 2009**[13]	**Faro, 2004**[7]
Appropriate study design?	Positive	Positive	Positive	Positive	Positive	Positive	Negative
Justified sample size?	Positive	Negative	Negative	Negative	Negative	Negative	Negative
Sample taken from appropriate population?	Positive	Positive	Unclear	Unclear	Positive	Unclear	Positive
Appropriate selection process?	Positive	Positive	Unclear	Unclear	Positive	Unclear	Positive
Appropriate variables and risk factors measured?	Positive	Positive	Negative	Negative	Positive	Positive	Positive
Variables and risk factor measured correctly?	Positive	Unclear	Unclear	Negative	Positive	Unclear	Positive
Methods sufficiently described?	Positive	Unclear	Positive	Negative	Positive	Positive	Positive
Appropriate time between taking images?	Unclear	Positive	Unclear	Positive	Positive	Positive	Negative
Did response rate raise concerns about bias?	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear
Results presented for all analyses described?	Positive	Positive	Unclear	Negative	Positive	Positive	Positive
Authors' conclusions justified by results?	Positive	Positive	Positive	Positive	Positive	Positive	Positive
Did funding or conflict affect authors' interpretation?	Positive	Positive	Unclear	Unclear	Positive	Positive	Positive
Axis Score /12	9	7	3	3	9	6	7
Rating	High	Moderate	Low	Low	High	Moderate	Moderate

Green	Positive
Yellow	Unclear
Red	Negative

Study description

Study characteristics including sample descriptions, disease characteristics, and methodology are shown in Table 3. Six arm positions were analyzed across included studies. These include: habitual standing, 30° or 45° active flexion, 30° passive flexion, fists to clavicle, and hands on wall. The most common positions reported in comparison studies were habitual standing (5 studies [13, 14, 25–27]), fists on clavicle (5 studies [7, 13, 25–27]), and active positions where the arms are raised and unsupported (3 studies [7, 13, 14]) (Table 3). The most commonly measured spinal alignment parameters were kyphosis (5 studies [7, 13, 16, 25, 27]), lordosis (5 studies [7, 13, 16, 25, 27]), and SVA (4 studies [7, 13, 14, 16]) (Table 4). Descriptive and comparative statistics for each of the imaging spine alignment outcomes extracted for the different positions are presented in Table 4.

Other spino-pelvic parameters were also assessed. Two studies assessed pelvic incidence, sacral slope, and pelvic tilt [7, 16] comparing Active 45° or Hands on wall to the Clavicle position, respectively (Online Resource 1). Further, Pasha et al. evaluated frontal balance, lateral pelvic tilt (LPT) and, and anterior pelvic plane (APP) inclination between Hands on wall and the Clavicle position [16]. Pasha et al. and Faro et al. both detected a significant sacral slope degree increase comparing the hands on wall and active 45°, respectively, to the clavicle position ($p < 0.05$) [7, 16] Wojciech et al. found no systematic differences for trunk

Table 2 Levels of evidence summary statements based on quality assessment and consistency of results among studies

Options	
Strong	Consistent results (≥ 75%) from at least 2 high-quality studies
Moderate	1 high-quality study and consistent findings (≥ 75%) in 1 or more low-quality studies
Limited	Findings in 1 high-quality study cohort or consistent results (≥ 75%) among low-quality studies
Insufficient	Findings in 1 low-quality study cohort
No	No study identified
Conflicting	Inconsistent results irrespective of study quality

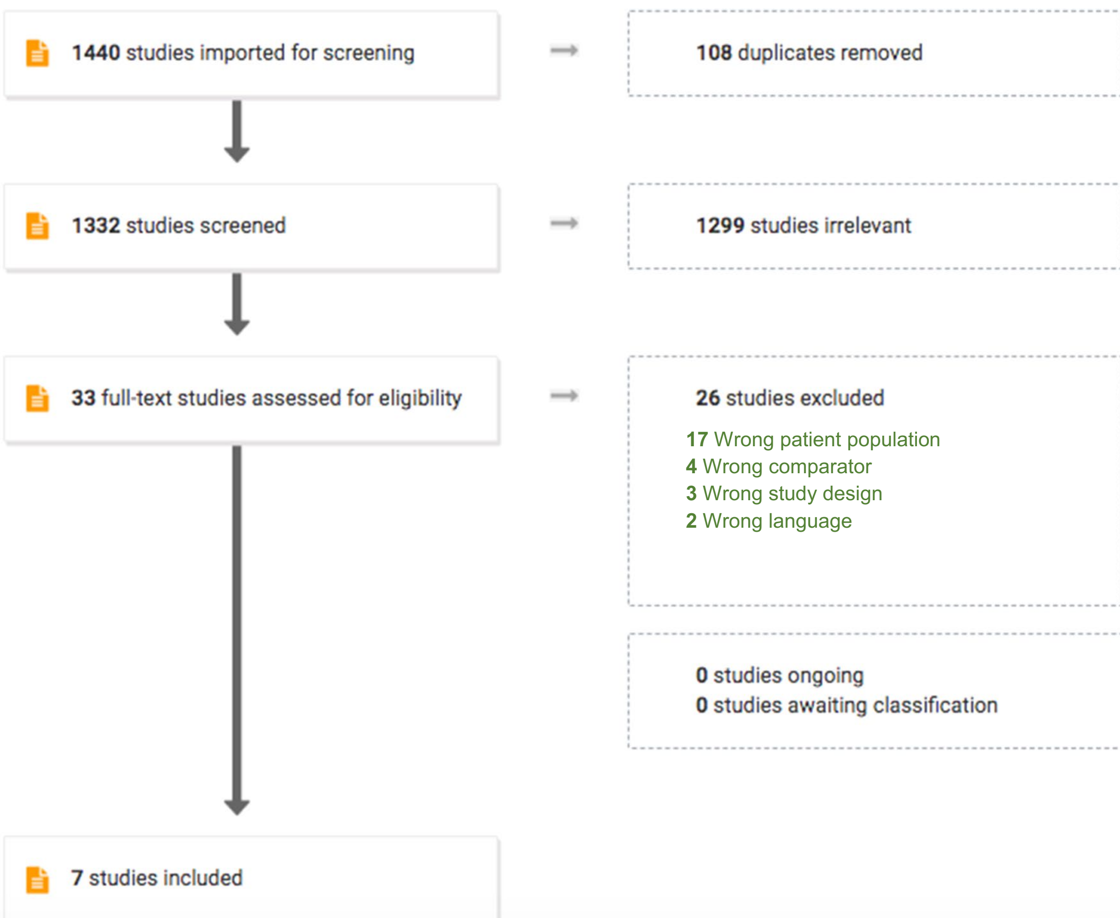


Fig. 1 PRISMA study selection flow diagram

Table 3 Study characteristics

Study	Population				Disease characteristics		Methodology	
	Sample size = N	Age (yrs); Mean ± SD (Min–Max Range)	Sex; Count, %	Count, % of Cohort within Dx Category	Curve Severity (°) Mean ± SD (Min–Max Range) Count, % Within Categories	Curve Types; Category, Count (%) for each type	Imaging Method Used	Arm position(s) used and description
Faro, 2004 [7]	50	14.7 ± 2.3	42 F, 84%	50, 100% AIS	NA	NA	Lateral spine radiograph	45° FLEXED: arms forward flexed at shoulders to ≈45° with elbows fully extended. CLAVICLE: fists on ipsilateral clavicles with elbows fully flexed.
Marks, 2009 [14]	22	13 ± 2 (12–20)	22 F, 100%	22, 100% healthy	Non-scoliotic	NA	Reflective markers, 8-camera infrared motion capture system	CONTROL: arms resting on either side. 30° ACTIVE: standing with active shoulder flexion to 30° and elbows extended. 30° PASSIVE: standing with passive shoulder flexion to 30° and elbows slightly flexed using "ski pole" type hand supports with rigid, stable bases placed in front and to the side. CLAVICLE: standing with the elbows fully flexed and each fist placed over the ipsilateral clavicle.
Marks, 2003 [13]	15	12.0 ± 1.9 10–14	15 F, 100%	15, 100% healthy	NA	NA	Reflective markers, 36-inch radiographs	RLX: Standing relaxed with arms at side; habitual standing posture. SF: Standing relaxed with 45° active shoulder flexion and elbows extended.
Asano, 2015 [27]	24	Mean 11.9	16 F, 67%	24, 100% school children screened for scoliosis	NA	NA	3D projection scanning system (SLS-1 David Vision)	NP: Natural dropped-arm. CP: Fists-on-clavicle.

Table 3 (continued)

Study	Population				Disease characteristics		Methodology	
	Sample size = N	Age (yrs); Mean ± SD (Min–Max Range)	Sex; Count, %	Count, % of Cohort within Dx Category	Curve Severity (°) Mean ± SD (Min–Max Range) Count, % Within Categories	Curve Types; Category, Count (%) for each type	Imaging Method Used	Arm position(s) used and description
Wojciech, 2013 [26]	694	10–18 years	275 F, 39.6%	NA	Non-scoliotic	NA	3D surface topography (3D Ortho-screen)	Hands hanging freely. Fingers on clavicles.
Abe, 2016 [25]	42	Mean 12.6	34 F, 81%	42, 100% school children screened for scoliosis	NA	NA	3D projection scanning system (SLS-1 David Vision)	NP: Natural dropped-arm. CP: fists-on-clavicle.
Pasha, 2016 [16]	37	10–18	NA	37, 100% AIS	Thoracic: 46° (0°-110°) Lumbar 30° (0°-90°)	95% of patients: Lenke 1 (A,B) or Lenke 3 (A, B, C,), one left-sided thoracolumbar curve, one Lenke 5C-type curve	EOS bi-planar low dose X-ray	CLAVICLE: knuckles on the ipsilateral clavicles while flexing the shoulders 45°. HANDS ON WALL: hands and forearms on the wall in front with a 90° shoulder and elbow flexion, keeping their distance arm length from the front wall.

AIS Adolescent idiopathic scoliosis, *CP* Fists-on-clavicle position, *F* Female, *NA* Not applicable, *NP* Natural dropped-arm position, *RLX* Standing relaxed, *SF* shoulder flexion

Table 4 Extracted descriptive statistics for each imaging outcome and comparison statistics among the positions compared in each study when available

Study	Whole Thoracic Kyphosis Angle (°) Mean ± SD (Min–Max), Statistical Differences Reported	T4/T5 – T11/T12 Kyphosis Angle (°) Mean ± SD (Min–Max), Statistical Differences Reported	T10-L2 Kyphosis Angle (°) Mean ± SD (Min–Max), Statistical Differences Reported	Lordosis Angle (°) Mean ± SD (Min–Max), Statistical Differences Reported	Sagittal Vertical Axis (mm) Mean ± SD (Min–Max), Statistical Differences Reported (- = posterior shift)	Curve Severity (°) Mean ± SD (Min–Max), Statistical Differences Reported	AVR (°); Mean ± SD (Min–Max), Statistical Differences Reported
Faro, 2004 [7]	ACTIVE 45° 32° ± 12° CLAVICLE 28° ± 14° ANOVA; CLAVICLE—ACTIVE 45° -5° ± 9°, $p = 0.014$	ACTIVE 45° 24° ± 12° CLAVICLE 20° ± 13° ANOVA; -4° ± 8°, $p = 0.013$	ACTIVE 45° 3° ± 7° CLAVICLE 1° ± 6° ANOVA; 2° ± 7°, $p = 0.269$	ACTIVE 45° -55° ± 28° CLAVICLE: -53° ± 27° ANOVA; 3° ± 7°, $p = 0.064$	ACTIVE 45° -50 ± 24 CLAVICLE -18 ± 23 ANOVA; 32 ± 26, $p < .001$	NA	NA
Marks, 2009 [13]	Normalized mean differences vs. HABITUAL: ACTIVE 30° -2° ± -7° CLAVICLE -3° ± -8° PASSIVE 30° -1° ± -6° ANOVA, Tukey: ACTIVE 30, CLAVICLE, PASSIVE 30 no different from HABITUAL $p > 0.05$	NA	NA	Normalized mean differences vs. HABITUAL: ACTIVE 30° 4° ± 7° CLAVICLE 4° ± 6° PASSIVE 30° 4 ± 5° ANOVA, Tukey ACTIVE 30°, CLAVICLE, PASSIVE 30° no different from HABITUAL, $p > 0.05$	Normalized mean differences vs. HABITUAL: ACTIVE 30° -46 ± 13 CLAVICLE -37 ± 19 PASSIVE 30° -11 ± 8 ANOVA, Tukey ACTIVE 30°, CLAVICLE < PASSIVE 30° < HABITUAL, $p < 0.05$	NA	NA
Marks, 2003 [14]	NA	NA	NA	NA	STANDING 9 ± 20 SF -46 ± 32 ANOVA, Bonferroni STANDING > SF, $p < 0.01$	NA	NA
Asano, 2015 [27]	HABITUAL 43.0° CLAVICLE 39.9° Normalized mean difference vs. HABITUAL CLAVICLE: -3.1° ± 5.4° HABITUAL > CLAVICLE, $p < 0.05$	NA	NA	HABITUAL 37.8° CLAVICLE 40.4° Normalized mean differences vs. HABITUAL CLAVICLE: 2.7° ± 3.4° HABITUAL < CLAVICLE, $p < 0.05$	Normalized mean differences vs. HABITUAL: CLAVICLE 24.7 ± 15, $p < 0.05$ 38% with posterior shift > 30 mm from HABITUAL to CLAVICLE	NA	NA

Table 4 (continued)

Study	Whole Thoracic Kyphosis Angle (°) Mean ± SD (Min–Max), Statistical Differences Reported	T4/T5 – T11/T12 Kyphosis Angle (°) Mean ± SD (Min–Max), Statistical Differences Reported	T10-L2 Kyphosis Angle (°) Mean ± SD (Min–Max), Statistical Differences Reported	Lordosis Angle (°) Mean ± SD (Min–Max), Statistical Differences Reported	Sagittal Vertical Axis (mm) Mean ± SD (Min–Max), Statistical Differences Reported (- = posterior shift)	Curve Severity (°) Mean ± SD (Min–Max), Statistical Differences Reported	AVR (°); Mean ± SD (Min–Max), Statistical Differences Reported
Abe, 2016 [25]	HABITUAL 40° CLAVICLE 36.7° Normalized mean differences vs. HABITUAL CLAVICLE: -3.1° ± 5.0° HABITUAL > CLAVICLE, $p < 0.05$	NA	NA	HABITUAL 35.9° CLAVICLE 39.9° Normalized mean differences vs. HABITUAL CLAVICLE 3.8° ± 3.7° CLAVICLE > HABITUAL $p < 0.05$	Mean change (HABITUAL to CLAVICLE) 31.2 ± 20 mm, $p < 0.05$ 54% showed posterior shift > 30 mm from HABITUAL to CLAVICLE	NA	NA
Wojciech, 2013 [26]	NA	NA	NA	Values not reported Systematic differences between standing with hands hanging freely < fingers on the clavicles	NA	NA	NA
Pasha, 2016 [16]	CLAVICLE: 33.6° ± 12.5° WALL: 29.5° ± 10.3° Paired t-test: CLAVICLE > WALL, $p < 0.05$	CLAVICLE 22.6° ± 10.6° WALL 19.8° ± 10.4° Paired t-test: CLAVICLE > WALL, $p < 0.05$	NA	L1-L5 WALL: 46.1° ± 13.9° Clavicle: 45.5° ± 13.1° L1-S1 WALL: 56.3° ± 13.7° CLAVICLE: 57.7° ± 13.1° Cervical Lordosis WALL: 5.9° ± 25.4° CLAVICLE: 7.6° ± 24.9° All paired t-tests: $p > 0.05$	CLAVICLE 3 ± 17 WALL -16 ± 29 Paired t-test: WALL more posterior than CLAVICLE, $p < 0.05$	Proximal thoracic: WALL 23.5° ± 12.6° CLAVICLE 27.7° ± 7.8° Main thoracic: WALL 50.3° ± 17.5° CLAVICLE 51.3° ± 17.2° Lumbar: WALL 43.9° ± 16.4° CLAVICLE 41.3° ± 17.7° All paired t-tests: $p > 0.05$	AVR Thoracic: CLAVICLE -12° ± 9.8° WALL -10.8° ± 16.5° Lumbar: CLAVICLE 13.7° ± 8.8° WALL 14.6° ± 9.9° All paired t-tests: $p > 0.05$

NA Not applicable, *SF* Standing with 45° shoulder flexion, *AVR* Axial vertebral rotation vertical inclination angle in the sagittal plane between standing and the clavicle position [26].

Quality appraisal

Of the seven studies, two were rated as high methodological quality, three as moderate, and two as low quality (Table 1). Our AXIS results commonly flagged questions regarding response rate, addressing biases, and the lack of descriptions justifying sample size. Alternatively, AXIS positively scored questions justifying results and conclusions, as well as appropriate study design choices.

Meta-analysis estimates

Kyphosis

- There is limited evidence from 2 moderate [13, 25] and 1 low quality studies [27] of a medium effect size of 0.78 [95% CI 0.48, 1.09, $p<0.01$] where kyphosis is smaller in the clavicle position when compared to habitual standing. (Fig. 2a) This analysis had low heterogeneity ($I^2=0\%$).
- Similarly, there is moderate evidence from 1 high [16] and 2 moderate quality studies [7, 13] of a non-significant and negligible effect size of 0.03 [95% CI − 0.38, 0.45, $p=0.88$] for difference in kyphosis between the clavicle compared to the active position (Fig. 2b). This analysis has substantial heterogeneity ($I^2=56\%$).

Lordosis

- There is limited evidence from 2 moderate [13, 25] and 1 low quality study [27] of a large effect size of − 1.21 [95% CI − 1.58, − 0.85, $p<0.01$] where lordosis is larger in the clavicle position compared to habitual standing (Fig. 2c). This analysis has low heterogeneity ($I^2=20\%$).
- There is moderate evidence from 1 high [16] and 2 moderate quality studies [7, 13] of a non-significant and negligible effect size of − 0.06 [95% CI − 0.32, 0.21, $p=0.68$] about the difference in lordosis between the clavicle compared to the active positions (Fig. 2d). This analysis has low heterogeneity ($I^2=0\%$).

SVA

- There is limited evidence from 2 moderate [13, 25] and 1 low quality study [27] of a large mean difference of 30.59 mm [95% CI 23.91, 37.27, $p<0.01$] where the SVA is shifted more posteriorly in the clavicle position compared to habitual standing (Fig. 2e). This analysis however presented substantial heterogeneity ($I^2=67\%$).
- There is also moderate evidence from 1 high [16] and 2 moderate quality studies [7, 13] of a significant but small mean difference of − 2.01 mm [95% CI − 3.38, − 0.64, $p=0.004$] where SVA is shifted more posteriorly in active positions compared to the clavicle position (Fig. 2f). This analysis has substantial heterogeneity ($I^2=83\%$).

Level of evidence summary statements

A total of 24 strength of evidence summary statements were formulated based on the number and the quality of studies to include the evidence from studies contributing results which could not be meta-analysed with those in the meta-analysis that examined each spinal alignment outcome between standing positions (Table 5). No summary statement offered strong evidence, 14 offered limited strength and 7 moderate strength of evidence. Sixteen statements demonstrated evidence of no differences, two statements demonstrated conflicting evidence, and one insufficient evidence statement between compared positions.

Overall, for comparisons to habitual standing, one statement showed no significant differences vs habitual standing in whole thoracic kyphosis in Passive 30° and Active 30°. One statement each showed significant increases in lordosis in the clavicle position and significant posterior shifts in SVA in Active 45° or 30°, Passive 30° and Clavicle compared to habitual standing. Other summary statements for comparisons to habitual standing were either conflicting (Kyphosis vs Clavicle) or showed no difference (kyphosis and lordosis vs Passive and Active 30°).

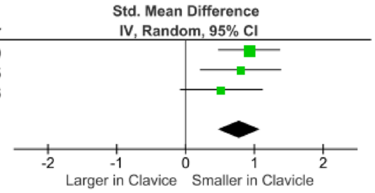
Summary statements about comparisons of elevated arms positions to the clavicle positions found: decreased T4/T5 kyphosis with Hands on wall and Active 45°; posterior shift of SVA with Active 30° or 45° and Hands on wall; decreased sacral slope in Active 45° and Hands on wall; and decreased Sagittal T1 tilt angle in Hands on wall. Other summary statements including comparisons among arms-elevated positions and Clavicle were either conflicting (whole kyphosis vs Passive 30°, Active 30° or 45° and Hands on wall) or showed no difference (lordosis for Active 30° or 45° and Hands on wall; lumbar and thoracic AVR or apical vertebral translation (AVT) in Hands on wall; pelvic incidence angle in Active 45° and Hands on wall; in four other spino-pelvic parameters in Hands on wall and one other spino-pelvic parameter in Active 45°).

Summary statements comparing Active 30° to Passive 30° found no differences in kyphosis and lordosis but a posterior SVA shift in Active compared to Passive 30°.

a. Standardized mean difference in kyphosis between habitual standing and clavicle

Study or Subgroup	Habitual Standing Mean	SD	Total	Clavicle Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI	Year
Marks, 2009	40	0.1	42	36.7	5	42	46.6%	0.92 [0.47, 1.38]	2009
Asano, 2015	43	0.1	24	39.9	5.4	24	27.2%	0.80 [0.21, 1.39]	2015
Abe, 2016	0	0.1	22	-3	8	22	26.2%	0.52 [-0.08, 1.12]	2016
Total (95% CI)			**88**			**88**	**100.0%**	**0.78 [0.48, 1.09]**	

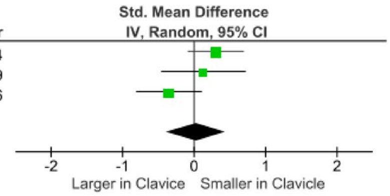
Heterogeneity: Tau² = 0.00; Chi² = 1.11, df = 2 (P = 0.57); I² = 0%
Test for overall effect: Z = 4.99 (P < 0.00001)



b. Standardized mean difference in kyphosis between active and clavicle positions

Study or Subgroup	Active Mean	SD	Total	Clavicle Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI	Year
Faro, 2004	32	12	50	28	14	50	38.7%	0.30 [-0.09, 0.70]	2004
Marks, 2009	-2	7	22	-3	8	22	26.9%	0.13 [-0.46, 0.72]	2009
Pasha, 2016	29.5	10.3	37	33.55	12.5	37	34.4%	-0.35 [-0.81, 0.11]	2016
Total (95% CI)			**109**			**109**	**100.0%**	**0.03 [-0.38, 0.45]**	

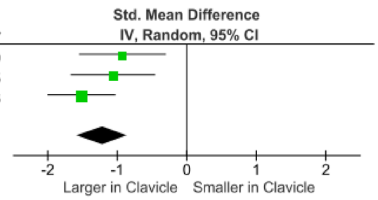
Heterogeneity: Tau² = 0.08; Chi² = 4.58, df = 2 (P = 0.10); I² = 56%
Test for overall effect: Z = 0.15 (P = 0.88)



c. Standardized mean difference in lordosis between habitual standing and clavicle

Study or Subgroup	Habitual Standing Mean	SD	Total	Clavicle Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI	Year
Marks, 2009	0	0.1	22	4	6	22	28.4%	-0.93 [-1.55, -0.30]	2009
Asano, 2015	37.8	0.1	24	40.4	3.4	24	29.7%	-1.06 [-1.67, -0.46]	2015
Abe, 2016	35.9	0.1	42	39.9	3.7	42	41.9%	-1.51 [-2.00, -1.03]	2016
Total (95% CI)			**88**			**88**	**100.0%**	**-1.21 [-1.58, -0.85]**	

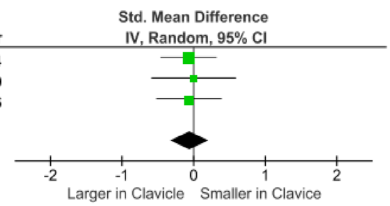
Heterogeneity: Tau² = 0.02; Chi² = 2.50, df = 2 (P = 0.29); I² = 20%
Test for overall effect: Z = 6.49 (P < 0.00001)



d. Standardized mean difference in lordosis between active positions and clavicle

Study or Subgroup	Active Mean	SD	Total	Clavicle Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI	Year
Faro, 2004	-55	28	50	-53	27	50	45.9%	-0.07 [-0.46, 0.32]	2004
Marks, 2009	4	7	22	4	6	22	20.2%	0.00 [-0.59, 0.59]	2009
Pasha, 2016	5.9	25.4	37	7.6	24.9	37	33.9%	-0.07 [-0.52, 0.39]	2016
Total (95% CI)			**109**			**109**	**100.0%**	**-0.06 [-0.32, 0.21]**	

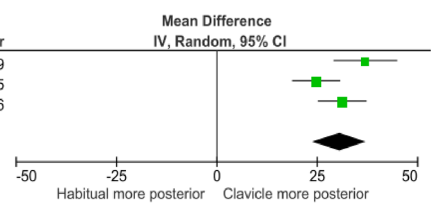
Heterogeneity: Tau² = 0.00; Chi² = 0.04, df = 2 (P = 0.98); I² = 0%
Test for overall effect: Z = 0.41 (P = 0.68)



e. Mean difference in SVA (mm) between the habitual standing and clavicle position

Study or Subgroup	Habitual Standing Mean	SD	Total	Clavicle Mean	SD	Total	Weight	Mean Difference IV, Random, 95% CI	Year
Marks, 2009	0	0.1	22	-37	19	22	29.2%	37.00 [29.06, 44.94]	2009
Asano, 2015	0	0.1	24	-24.7	15	24	35.5%	24.70 [18.70, 30.70]	2015
Abe, 2016	0	0.1	42	-31.2	20	42	35.3%	31.20 [25.15, 37.25]	2016
Total (95% CI)			**88**			**88**	**100.0%**	**30.59 [23.91, 37.27]**	

Heterogeneity: Tau² = 23.38; Chi² = 6.13, df = 2 (P = 0.05); I² = 67%
Test for overall effect: Z = 8.97 (P < 0.00001)



f. Mean difference in SVA (mm) between active positions and clavicle

Study or Subgroup	Active Mean	SD	Total	Clavicle Mean	SD	Total	Weight	Mean Difference IV, Random, 95% CI	Year
Faro, 2004	-5	2.4	50	-1.8	2.3	50	34.1%	-3.20 [-4.12, -2.28]	2004
Marks, 2009	-4.6	1.3	22	-3.7	1.9	22	33.7%	-0.90 [-1.86, 0.06]	2009
Pasha, 2016	-1.6	2.9	37	0.3	1.7	37	32.2%	-1.90 [-2.98, -0.82]	2016
Total (95% CI)			**109**			**109**	**100.0%**	**-2.01 [-3.38, -0.64]**	

Heterogeneity: Tau² = 1.21; Chi² = 11.55, df = 2 (P = 0.003); I² = 83%
Test for overall effect: Z = 2.87 (P = 0.004)

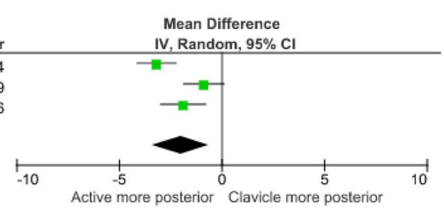


Fig. 2 **a–f** Meta-analysis forest plots for comparisons of pairs of position of interest

Table 5 Strength of evidence summary statements based on combining studies contributing results which could not be meta-analysed with those in the meta-analysis and based on their quality assessment comparing specific outcomes between imaging positions

Strength of evidence	# of Studies of specific quality and reported effects	Effect	Outcome measure	Positions compared
Conflicting	1 high [16], 1 moderate quality study [7] with sig diff. & 1 moderate quality study with no sig. diff. [13]	Decreases Or no difference	Whole thoracic kyphosis	Passive 30°, Active 45°, Active 30°, Hands on wall vs. Clavicle
Conflicting	1 low [27], 1 moderate quality study [25] with sig. diff. & 1 moderate quality studies with no sig. diff. [13]	Decreases Or no differences	Whole thoracic kyphosis	Clavicle vs. Habitual
Limited	1 moderate with no sig. diff. [13]	No difference	Whole thoracic kyphosis	Passive 30° vs. Active 30°
Limited	1 moderate with no sig. diff. [13]	No difference	Whole thoracic kyphosis	Passive 30°, Active 30° vs. Habitual
Limited	1 moderate with no sig. diff. [7]	No difference	T10-L2 kyphosis	Active 45° vs. Clavicle
Moderate	1 high quality [16] and 1 moderate quality study with sig. diff [7]	Decreases	T4/T5 kyphosis	Hands on wall, Active 45° vs. Clavicle
Limited	1 moderate with no sig. diff. [13]	No difference	Lordosis	Active 30°, Passive 30° vs. Habitual
Limited	2 low [26, 27], and 1 moderate quality study [25] with sig. diff. & 1 moderate quality study with no sig. diff. [13]	Increases	Lordosis	Clavicle vs. Habitual
Moderate	1 high [16], 2 moderate quality studies with no sig. diff. [7, 13]	No difference	Lordosis	Active 45°, Active 30°, Hands on wall vs. Clavicle
Limited	1 moderate quality study with no sig. diff. [13]	No difference	Lordosis	Active 30° vs. Passive 30°
Moderate	1 high [14], 2 moderate [13, 25] and 1 low quality study [27]with sig. diff	Posterior shift	SVA	Active 45°, Active 30°, Passive 30°, Clavicle vs. Habitual
Moderate	1 high [16], 1 moderate quality study with sig diff. [7] and 1 moderate with no sig. diff. [13]	Posterior shift	SVA	Active 45°, Active 30°, Hands on wall vs. Clavicle
Limited	1 moderate quality study with sig. diff. [13]	Posterior shift	SVA	Active 30° vs. Passive 30°
Insufficient	1 low quality study with no sig. diff. [26]	No differences	Sagittal trunk vertical inclination angle	Clavicle vs. Habitual
Limited	1 high quality study with no sig. diff. [16]	No differences	Curve Angle	Hands on wall vs. Clavicle
Limited	1 high quality study with no sig. diff [16]	No differences	Thoracic AVR & AVT	Hands on wall vs. Clavicle
Limited	1 high quality study with no sig. diff [16]	No differences	Lumbar AVR & AVT	Hands on wall vs. Clavicle
Moderate	1 high [16], 1 moderate quality study [7] with no sig. diff	No differences	(Sagittal) Pelvic incidence angle	Active 45°, Hands on wall, Clavicle
Moderate	1 high [16], 1 moderate quality study [7] with sig. diff	Decreased	(Sagittal) Sacral slope angle	Active 45°, Hands on wall vs. Clavicle

Table 5 (continued)

Strength of evidence	# of Studies of specific quality and reported effects	Effect	Outcome measure	Positions compared
Moderate	1 high quality study with sig. diff. [16] and 1 moderate quality study with no sig. diff. [7]	No difference	(Sagittal) Pelvic Tilt angle	Hands on wall, Active 45° vs. Clavicle
Limited	1 high quality study with sig. diff. [16]	Decreased	(Sagittal) T1 tilt angle	Hands on wall vs. Clavicle
Limited	1 high quality study with no sig. diff [16]	No differences	(Sagittal) L4 tilt angle	Hands on wall vs. Clavicle
Limited	1 high quality study with no sig. diff [16]	No differences	Spinal height	Hands on wall vs. Clavicle
Limited	1 high quality study with no sig. diff. [16]	No differences	Lateral pelvic tilt angle	Hands on wall vs. Clavicle

Sig. diff. Significant differences, *SVA* Sagittal Vertical Axis, *AVR* Axial Vertebral Rotation, *AVT* Apical Vertebral Translation

For eight of the parameters of interest stated a priori, summary statements were formulated to quickly identify positions tested to date and help researchers determine which positions have not yet been studied (no evidence) (Table 6). Positions that have not yet been reported depending on the alignment parameters are hands actively raised above the shoulders, hands on wall or blocks, hands to chin, hands to cheeks, and hands to eyebrows. Among hand raised positions, which could allow assessing skeletal maturity, only hands on wall has been previously studied [16]. Studies seldom reported on all spinal parameters we identified as of interest a priori, most notably, frontal (maximum curve angle) and transverse angles have been rarely studied (AVR twist) (Table 6). Only one study to date assessed the effects on curve angle, AVT, and AVR [16].

Discussion

The results of our systematic review found limited evidence on arm positions in adolescents that compared spinal parameters to habitual standing. Of the few positions that are discussed in the existing literature, our meta-analysis shows there are also mixed results when using these positions. The spinal parameters most commonly discussed are kyphosis, lordosis, and SVA—all sagittal parameters. We prioritized finding the effect of positioning on sagittal parameters, but little to no research has been published on the effect of arm positions on frontal or transverse plane parameters like Cobb angle, AVT, and AVR or AVR twist, respectively. Our meta-analysis results show that the most commonly used arm position during radiography clinically, the clavicle position, significantly decreases kyphosis and increases lordosis compared to habitual standing. Consequently, this position also significantly shifts SVA posteriorly. Our meta-analysis results show that active arm positions, when compared to the clavicle position, show non-significant decreases in kyphosis and increases in lordosis (Fig. 2b, d). Further, active positions significantly shift SVA posteriorly when compared to the clavicle position (Fig. 2f). There are a number of positions that have not been tested in the literature that would allow for the hands to be exposed for the scoring of skeletal maturity. Pasha et al. reported results for the hands-on wall position, and is the lone study comparing a position that could expose the hands but did not compare spinal alignment parameters in this position to habitual standing [16].

It is important to ensure that arm positioning during radiography is not having significant effects on spinal alignment parameters for a number of reasons. If conclusions about treatment for patients with AIS is made based upon radiograph measurements that are not accurately reflecting habitual standing or the position adopted during prior radiographs, this could result in incorrect treatment options recommendation in the clinic. Accurate parameters are needed to construct custom braces and plan surgeries for AIS. If these are inaccurate based on changing arm positioning, brace construction may be inappropriate and cause this treatment to be uncomfortable and unsuccessful. If patients with AIS are nearing indications of surgery, which is defined by the SRS as a curve degree of over 45°–50° and/or those who are at high risk of continued worsening, precise radiograph results are imperative to determine if surgery will be recommended [28]. Similarly, if patients are consistently changing arm positions over the course of treatment, it may be hard to determine curve degree over time and adequately detect progression. For these reasons, it is critical to guarantee the

Table 6 Outcome characteristics and position comparisons of interest NOT yet reported in literature

Strength of evidence	# of Studies of specific quality and reported effects	Outcome measure	Positions compared
No evidence	No studies	T4/T5 kyphosis	Positions other than Habitual, Clavicle, Passive 30°, hands on wall, Active 45°
No evidence	No studies	Whole kyphosis	Positions other than Habitual, Clavicle, Passive 30°, hands on wall, Active 30° or 45°
No evidence	No studies	T10-L2 kyphosis	Positions other than Habitual, Passive 30°, Active 45°
No evidence	No studies	Lordosis or SVA	Positions other than Habitual, Clavicle, Passive 30°, Hands on wall, Active 30 or 45°
No evidence	No studies	AVR or AVT	Positions other than Clavicle, Hands on wall
No evidence	No studies	Pelvic tilt, Pelvic Incidence, or Sacral slope	Positions other than Clavicle, Hands on wall, Active 45°
No evidence	No studies	T1 tilt, L4 tilt, Spinal height, Lateral pelvic tilt	Positions other than Clavicle, Hands on wall
No evidence	No studies	Cobb angle	Positions other than Clavicle, Hands on wall

SVA Sagittal Vertical Axis, *AVR* Axial Vertebral Rotation, *AVT* Apical Vertebral Translation

arm position used during radiography is consistent and a reflection of habitual standing parameters.

A 2017 literature review compared arm positions during radiography [29]. The review included 22 studies using radiograph measurements and 16 studies that used photogrammetry measurements. All populations including adults, adolescents, scoliotic, and healthy participants were included. Our review differs most notably from this review because we included *only* the adolescent populations within the search. Our reviews retrieved only one study in common and, we did not miss any relevant articles that were retrieved by Okazaki and Porto [29]. This 2017 literature review included the comparison of radiography and photogrammetry imaging methods and was only interested in extracting thoracic kyphosis and lordosis measurements. Like our review, it was concluded there is a lack of standardized patient positioning during imaging. Okazaki and Porto suggested that, due to the lack of studies with comparisons among different arm positioning, radiographs be performed with arms flexed and fists resting on the clavicles, ensuring changes in the sagittal vertical axis and pelvic parameters do not occur [29]. Although a conclusive statement was made, it remains unclear how to ensure that any changes are not occurring in the SVA and/or other pelvic parameters during imaging in the clavicle position. Our review results concur with Faro et al., who stated that although the fingers on clavicle position is commonly used in clinics and in the literature [7], this position is not a reflection of habitual standing due to significant decreases in kyphosis, increases in lordosis, and shifts in SVA reported in adolescents.

The literature found in this review did not use consistent imaging methods. Only three studies used radiographs to detect differences in spinal parameters [7, 14, 16]. The remaining studies used varying surface topography methods [25–27] or reflective markers [13]. Across the studies we reviewed, only one justified the sample size [16]. Among studies that did not justify sample, the size ranged from 15 to 695 participants. Small samples (< 30 participants) may be insufficient to detect clinically important differences between positions. The choice and description of methods used for measuring the different spinal parameters were found to be inconsistent across the literature. Due to methodological inconsistencies across the studies we reviewed, and according to AXIS scoring, only two studies were deemed high quality, three were deemed moderate, and two were deemed low quality studies. It is recommended for future research to use consistent imaging methods and spinal parameter measuring techniques when comparing arm positions to habitual standing. The SRS Radiographic Measurement Manual and the SRS-Schwab Adult Spinal Deformity Classification offer clear instructions obtaining relevant measurements and we recommend these measurements be used in future studies [6, 30]. Sample size estimation strategies should be presented, and studies planned with adequate power to detect clinically important differences in the relevant parameters used in comparing positions.

The summary statements of our review show there are non-significant effects on lordosis among the commonly used arms elevated positions (clavicle, active, and passive positions). However, our statement comparing the clavicle position to habitual standing is in agreement with our meta-analysis, by showing a significant increase in lordosis measurements in the clavicle position compared to habitual standing. This suggests that most arm-elevated positions may change the spinal sagittal alignment compared to habitual standing. One study in our review also showed a significant decrease in kyphosis during the hands-on wall position compared to the clavicle position, but our meta-analysis did not show any significant differences in kyphosis measurements when comparing similar active positions [16]. Our summary statements show a conflicted strength of evidence with two studies [25, 27] showing significant decreases and one finding no difference [13] in whole thoracic kyphosis when comparing the clavicle position to habitual standing. Our meta-analysis, however, shows significant decreases in kyphosis across the literature when combining the evidence comparing these positions. Most of the literature shows significant posterior shifts in SVA in all positions with elevated arms measured compared to habitual standing [7, 13, 14] (Table 4). When the arms are held in active positions, there appears to be more important posterior shifts in the sagittal profile, and thus, such positions do not represent habitual standing. Similarly, the literature shows that the clavicle position, when compared to active positions and when the hands are held on the wall, are also not interchangeable [7, 16]. Only one study directly compared active and passive positions, showing that while there are no significant effects on kyphosis and lordosis, active arm elevation led to a significantly larger posterior shift in SVA [13]. The majority of the literature found on this topic did not compare enough positions and does not report on all relevant spinal parameters (Table 6). Only one paper addresses sex differences without reporting data, stating differences between the clavicle position and standing were significant regardless of sex [26]. A significant gap in knowledge remains.

Our review was specific to adolescent populations, limited to arm positions while standing. By eliminating adult populations and sitting or lying positions, we limited results in our search. This being said, we only included adolescents because they are the population effected by AIS for which treatment decisions should be made based on regular radiograph comparisons during growth. We could have missed studies in our search due to excluding languages other than English. Including more databases could have resulted in finding more research. Articles and abstracts were screened by two independent and blinded reviewers. Both reviewers were novice but reached good levels of agreement. Our meta-analysis results may be affected by the use of differing measurement methodologies between studies. Notably, the standardized mean difference was reported for kyphosis and lordosis analysis due to a difference in the reporting of these parameters between the studies. Our chosen quality appraisal tool, AXIS and scoring strategy, focuses mainly on the methodological quality of the chosen methods and analysis and is less focused on the quality of reporting [21]. We were then able to accurately determine the methodological quality of the studies reported.

Our review shows sagittal spinal parameters, most notably posterior shifts in SVA, are more prone to change when raising the arms in comparison to habitual standing measurements. Similarly, there are reported differences among positions that raise the arms and therefore prevent these positions from being used interchangeably. Therefore, spinal parameters in radiographs using these positions do not accurately reflect habitual standing. No position exposing the hands during imaging have been compared to habitual standing, and only the hands on wall position has been compared to other arm positions. Limited literature in this topic that is specific to AIS reinforces the need for more research and it remains unclear which arm position best represents habitual standing during radiography in patients with AIS.

Appendix

See Figs. 3, 4, 5 and 6.

Fig. 3 CINHAL search strategy

Search Terms	
S1	idiopathic scoliosis
S2	(MH "Spinal Curvatures+")
S3	spin* disorder or spin* deform*
S4	S1 OR S2 OR S3
S5	"Coronal alignment"
S6	"Sagittal alignment"
S7	"Cobb angle*" OR "Cobb Degree*"
S8	"Curve angle*" OR "Curvature* angle*"
S9	"Kyphosis"
S10	"Lordosis"
S11	"Rotation angle*" OR "Vertebr* rotation"
S12	"Coronal *balance*"
S13	"Decompensation"
S14	"Sagittal balance"
S15	S5 OR S6 OR S7 OR S8 OR S9 OR S10 OR S11 OR S12 OR S13 OR S14
S16	"Arm position*"
S17	(MH "Patient Positioning") OR "patient position*"
S18	(MH "Upper Extremity+") OR "Upper Limb*" OR "Upper Extremit*"
S19	"(Finger* OR hand* OR knuckle*) N3 (chin OR eye* OR forehead OR cheek* OR zygomatic OR ear* OR clavicle* OR nose)"
S20	S16 OR S17 OR S18 OR S19
S21	S4 AND S15 AND S20
S22	(MH "Diagnostic Imaging") OR (MH "Imaging, Three-Dimensional+") OR (MH "Magnetic Resonance Imaging") OR (MH "Radiography") OR (MH "Fluoroscopy") OR (MH "Radiography, Thoracic") OR (MH "Ultrasonography")
S23	Radiograph* OR fluoroscopy OR Ultrasonogr* OR Echography OR Magnetic resonance imag* OR MRI
S24	S22 OR S23
S25	S21 AND (S22 OR S23 OR S24)
S26	(MH "Cerebral Palsy") OR ""cerebral palsy""
S27	(MH "Muscular Dystrophy+") OR (MH "Myotonic Dystrophy") OR ""muscular dystrophy"" OR (MH "Muscular Dystrophy, Emery-Dreifuss") OR (MH "Muscular Dystrophy, Duchenne+") OR (MH "Becker Muscular Dystrophy") OR (MH "Muscular Dystrophy, Facioscapulohumeral") OR (MH "Muscular Dystrophy, Oculopharyngeal")
S28	(MH "Arthroplasty+") OR "arthroplasty"
S29	(MH "Marfan Syndrome") OR ""marfan syndrome""
S30	(MH "Osteogenesis Imperfecta") OR ""osteogenesis imperfecta""
S31	S26 OR S27 OR S28 OR S29 OR S30
S32	S25 NOT S31
S33	(MH "Case Studies") OR ""Case Report""
S34	S32 NOT S33
TOTAL: 59 papers	
Ran: June 29, 2022	

Search Term
1. Idiopathic Scoliosis.mp.
2. exp Spinal Curvatures/
3. (spin* disorder* or spin* deform*).mp.
4. 1 or 2 or 3
5. radiography/ or fluoroscopy/
6. imaging, three-dimensional/ or ultrasonography/
7. (Radiograph* or Fluoroscopy or Ultrasonogr* or Echography or Magnetic resonance imaging or MRI or EOS Imaging).mp.
8. nuclear magnetic resonance imaging.mp.
9. 5 or 6 or 8
10. 4 and 9
11. Coronal alignment.mp.
12. sagittal alignment.mp.
13. Cobb angle*.mp.
14. Curve angle*.mp.
15. exp Kyphosis/ or exp Lordosis/
16. Kyphosis angle*.mp.
17. Lordosis angle*.mp.
18. Rotation angle*.mp.
19. Vertebr* rotation.mp.
20. exp Postural balance/
21. Coronal balance.mp.
22. Decompensation.mp.
23. Sagittal balance.mp.
24. 11 or 12 or 13 or 14 or 15 or 16 or 17 or 18 or 19 or 20 or 21 or 22 or 23
25. patient positioning.mp. or exp Patient Positioning/
26. Body Position*.mp.
27. Arm positioning.mp.
28. Upper limb.mp. or exp Upper Extremity/
29. ((Finger* or hand* or knuckle*) adj2 (chin or eye* or forehead or cheek* or zygomatic or ear* or clavicle* or nose)).mp. [mp=title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms]
30. 25 or 26 or 27 or 28 or 29
31. 10 and 24 and 30
32. Cerebral palsy.ti. or exp Cerebral Palsy/
33. exp progressive muscular dystrophy/ or exp myotonic dystrophy protein kinase/ or exp facioscapulohumeral muscular dystrophy/ or Dystrophy.ti. or exp muscular dystrophy/ or exp Fukuyama congenital muscular dystrophy/ or exp Duchenne muscular dystrophy/ or exp Becker muscular dystrophy/ or exp myotonic dystrophy/ or exp Emery Dreifuss muscular dystrophy/ or exp dystrophy/
34. exp Arthroplasty/ or arthroplasty.mp.
35. Marfan syndrome.ti. or exp Marfan syndrome/
36. Osteogenesis imperfecta.ti. or exp osteogenesis imperfecta/
37. 32 or 33 or 34 or 35 or 36
38. 31 not 37
39. limit 38 to (human and english language)
40. Case Report.mp. or exp case report/
41. 39 not 40
Total papers found: 76
Ran: June 29, 2022

Fig. 4 Medline search strategy

Search Terms
1. Idiopathic Scoliosis.mp. or exp idiopathic scoliosis/
2. Scoliosis.mp. or exp scoliosis/
3. Spin* Disorder*.mp.
4. Spin* deform*.mp.
5. 1 or 2 or 3 or 4
6. Radiograph*.mp. or exp X ray film/ or exp radiography/
7. exp echography/ or Ultrasound Imaging.mp.
8. Fluoroscopy.mp. or exp fluoroscopy/
9. exp nuclear magnetic resonance imaging/ or Standing MRI.mp.
10. 6 or 7 or 8 or 9
11. 5 and 10
12. Coronal alignment.mp.
13. Sagittal alignment.mp.
14. exp Cobb angle/ or Cobb Angle*.mp.
15. Curve angle*.mp.
16. exp kyphosis/ or Kyphosis angle*.mp.
17. exp rotation/ or Rotation angle*.mp.
18. exp lordosis/ or Lordosis angle*.mp.
19. Coronal balance.mp.
20. Decompensation.mp.
21. Sagittal balance.mp.
22. 12 or 13 or 14 or 15 or 16 or 17 or 18 or 19 or 20 or 21
23. exp patient positioning/ or Arm positioning.mp.
24. exp body position/ or Position*.mp.
25. Upper Extremity.mp. or exp upper limb/
26. 23 or 24
27. 25 and 26
28. ((Finger* or hand* or knuckle*) adj2 (chin or eye* or forehead or cheek* or zygomatic or ear* or clavicle* or nose)).mp. [mp=title, abstract, heading word, drug trade name, original title, device manufacturer, drug manufacturer, device trade name, keyword, floating subheading word, candidate term word]
29. 23 or 24 or 27 or 28
30. 5 and 10 and 22 and 29
31. Cerebral palsy.ti. or exp cerebral palsy/
32. exp progressive muscular dystrophy/ or exp myotonic dystrophy protein kinase/ or exp facioscapulohumeral muscular dystrophy/ or Dystrophy.ti. or exp muscular dystrophy/ or exp Fukuyama congenital muscular dystrophy/ or exp Duchenne muscular dystrophy/ or exp Becker muscular dystrophy/ or exp myotonic dystrophy/ or exp Emery Dreifuss muscular dystrophy/ or exp dystrophy/
33. exp arthroplasty/ or Arthroplasty.ti.
34. Marfan syndrome.ti. or exp Marfan syndrome/
35. 31 or 32 or 33 or 34
36. 30 not 35
37. limit 36 to (human and english language)
38. Osteogenesis imperfecta.ti. or exp osteogenesis imperfecta/
39. 37 not 38
40. Case Report.mp. or exp case report/
41. 39 not 40
Total: 316 papers
Ran: June 29, 2022

Fig. 5 Embase search strategy

Fig. 6 Web of science search strategy

Search Terms
1. Idiopathic scoliosis (Topic)
2. Spinal Curvatures (Topic)
3. TS=(Scoliosis OR "Spin* deform*" Or "spin* disorder*")
4. #1 OR #2 OR #3
5. TS=(Radiograph* OR Fluoroscopy OR Ultrasonogr* OR Echography or Magnetic resonance imaging OR MRI OR EOS Imaging)
6. TS=(Three-Dimensional Imaging)
7. TS=(nuclear magnetic resonance imaging)
8. #5 OR #6 OR #7
9. #4 AND #8
10. TS=(Coronal Alignment OR Sagittal alignment)
11. TS=(Cobb angle*)
12. TS=(Curve angle*)
13. TS=(Kyphosis OR Lordosis)
14. TS=(Kyphosis angle* OR Lordosis angle*)
15. TS=(Rotation angle*)
16. TS=(Vertebr* rotation)
17. TS=(Postural Balance OR Coronal Balance or Sagittal Balance)
18. TS=(Decompensation)
19. #10 OR #11 OR #12 OR #13 OR #14 OR #15 OR #16 OR #17 OR #18
20. TS=(Arm position*)
21. TS=(Body position)
22. TS=(Patient Positioning)
23. TS=(Upper limb OR Upper Extremity)
24. TS=((Finger* or hand* or knuckle*) NEAR/2 (chin or eye* or forehead or cheek* or zygomatic or ear* or clavicle* or nose))
25. #20 OR #21 OR #22 OR #23 OR #24
26. #9 AND #19 AND #25
27. TS=(Cerebral Palsy)
28. TS=(Muscular dystrophy OR progressive muscular dystrophy OR myotonic dystrophy protein kinase or facioscapulohumeral muscular dystrophy OR Dystrophy OR Fukuyama congenital muscular dystrophy OR Duchenne muscular dystrophy OR Becker muscular dystrophy OR myotonic dystrophy OR Emery Dreifuss muscular dystrophy OR dystrophy)
29. TS=(Osteogenesis imperfecta)
30. TS=(Marfan Syndrome)
31. TS=(Arthroplasty)
32. #27 Or #28 OR #29 OR #30 OR #31
33. #26 NOT #32
34. TS=(Case report)
35. #33 NOT #34
Total: 747 papers
Ran: June 29, 2022

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Data and/or code availability Data extraction information is provided within the paper and tables and supplementary data.

Declarations

Conflict of interest The authors have no competing interests to declare that are relevant to the content of this article.

Ethics approval Ethical approval is not required for this systematic review.

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